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Falls Lake Subsistence Sockeye Salmon Project 2004 Annual Report

by

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and

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Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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The Federal Subsistence Board, managed by U.S. Fish and Wildlife Service Office of Subsistence Management, approved the Falls Lake Sockeye Salmon Stock Assessment Project (Study Number FIS00-044). The project was funded by the U.S. Forest Service, and is a cooperative project between the U.S. Forest Service (USFS), the Alaska Department of Fish and Game (ADF&G), and the Organized Village of Kake (OVK). This annual report partially fulfills contract obligations for Sikes Act Contract (43-0109-0-0174).

The Division of Sport Fish Fishery Data Series was established in 1987 for the publication of technically oriented results for a single project or group of closely related projects. Since 2004, the Division of Commercial Fisheries has also used the Fishery Data Series. Fishery Data Series reports are intended for fishery and other technical professionals. Fishery Data Series reports are available through the Alaska State Library and on the Internet: http://www.sf.adfg.state.ak.us/statewide/divreports/html/intersearch.cfm This publication has undergone editorial and peer review.

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ABSTRACT

We determined a total harvest of 2,940 sockeye salmon (*Oncorhynchus nerka*) from a census of all sport and subsistence fishers in the Falls Lake marine terminal area in 2004, and we estimated 3,300 sockeye salmon (95% confidence interval 3,200–3,500) escaped to spawn in the lake. Despite a one-week midseason closure, daily escapement numbers were small until the fishery ended. We used a stratified, closed population model to estimate the number of sockeye salmon entering the lake. We also tagged fish on the spawning grounds, and used an open population model (Jolly-Seber) to estimate the sockeye spawning population. Compared with the closed population estimate of 3,300 sockeye salmon entering the lake, we estimated a spawning population of about 2,600 fish (95% confidence interval 2,400–2,900) within the study area using the open population model. By means of visual surveys, we estimated that these fish comprised 87% of all sockeye spawners in the lake, and from this percentage, we estimated a total spawning population of roughly 3,000 fish. The most likely reason for the small difference between the closed and open population estimates was that natural mortality reduced the size of the effective spawning population after fish entered the lake. We sampled sockeye smolt migrating out of Falls Lake and estimated about 75% were age-1 fish. Similarly, about 80% of sockeye adults in the 2004 escapement had one freshwater year (age-1.2 and age-1.3 fish). Both smolt and adult age compositions showed higher percentages of age-1 smolt than during the 1980s. Zooplankton biomass and numbers were lower than in previous years and in other similar sockeye-producing lakes in Southeast Alaska. The changes in smolt size and age composition suggest improved habitat conditions for sockeye fry, but with limited prey populations.

Key words: Sockeye salmon, *Oncorhynchus nerka*, subsistence, Falls Lake, Kake, escapement, smolt, mark-recapture, zooplankton

INTRODUCTION

The Falls Lake system produces a small but consistent run of sockeye salmon (*Oncorhynchus nerka*), which Kake residents harvest actively during mid-July. Falls Lake sockeye salmon have played an important role in the seasonal subsistence cycle of people from Kake, in the traditional (pre-European contact), historical, and modern periods (Goldschmidt et al. 1998; Firman and Bosworth 1990). The traditional Kake territory, which included bays and shorelines on Kuiu Island and portions of Kupreanof Island, the mainland, Admiralty Island, and Baranof Island, contained few sockeye salmon streams (Goldschmidt et al. 1998). Falls Lake was one of the most important of these, and was the site of seasonal fish camps through the early 1900s. Sometime after the present-day village of Kake was established, these fish camps were abandoned and Kake residents now travel about 50 km, across the exposed waters of lower Chatham Strait, to fish for sockeye salmon at Falls Lake. Because of the long, exposed crossing and lack of suitable anchorages around Falls Lake, most subsistence fishers try to travel from Kake during good weather and harvest their season’s supply of sockeye salmon in one day. In 2002, Kake residents and Alaska Department of Fish and Game (ADF&G) fishery managers negotiated to increase the daily possession limit for sockeye salmon to 50 fish at Falls Lake, in order to avoid the necessity for repeat trips (B. Davidson, ADF&G fisheries management biologist, 2002).

We have been estimating harvest and escapement of sockeye salmon, sockeye juvenile production, and lake habitat conditions in Falls Lake since 2001 in order to develop some baseline information to help guide management decisions about this stock. Falls Lake sockeye salmon escapements, juvenile populations, prey populations, and water chemistry measures were previously estimated in the 1980s during a fertilization study (Conitz et al. 2002). From 2001 to 2003, we estimated populations of 3,700–8,400 sockeye salmon returning to the marine area around the outlet of Falls Lake, out of which 30%–70% were harvested in the subsistence fishery (Conitz and Cartwright 2005). In the same period, estimated annual escapement was between 1,100 and 5,700 sockeye salmon. Because these escapement sizes are similar to those observed in the 1980s, fishery management biologists have judged these escapements to be adequate to sustain the population. However, because of the high exploitation rate on this small salmon run, the biologists have been closely monitoring the fishery. In addition, they have adjusted the season to try and reduce harvest at the beginning of the run (Conitz and Cartwright 2005).

Since 2003, we have used a trap at the top of the fish ladder to obtain daily in-season index counts and to mark sockeye salmon as they entered the lake (Conitz and Cartwright 2005). Because not all sockeye salmon enter Falls Lake through the fish ladder, this method does not provide a complete daily or seasonal count of escapement. Therefore, we sampled for marked fish on the spawning grounds, and estimated escapement using a stratified, closed population model (Arnason et al. 1996). In 2004, we marked fish with individual numbered tags in order to test certain assumptions of this model. A fundamental assumption in a closed population model is that probability of capture is the same for each fish; however, salmon runs present many opportunities for this assumption to be violated. At Falls Lake, probability of capture in the first sample (marking at the trap) may not be constant if the proportion of migrating sockeye salmon using the fish ladder changes from day to day. On the spawning grounds, gaps between sampling dates or changes in sampling conditions, such as high or low water levels, can result in unequal capture probabilities in the second sample (recapture of marked fish). Furthermore, the closure assumption must be relaxed in spawning salmon populations to allow death. In simulation studies, unequal capture probabilities combined with lack of closure due to death resulted in estimates that were biased high (Arnason et al. 1996). Use of numbered tags enabled us to construct a capture history for each tagged fish, estimate capture probabilities, and test model fit under several stratification schemes for marking and recapture samples.

In Falls Lake, as in most other sockeye systems, sockeye salmon enter the lake in midsummer and spend several weeks maturing in the deep water of the lake before coming up to shoreline areas or inlet streams to spawn. We conducted a separate mark-recapture study on the spawning grounds each year to estimate the sockeye spawning population in Falls Lake. We compared the spawning population estimate to the estimated number of fish entering the lake earlier in the season to test the accuracy of each estimate. In 2004, we used numbered tags and constructed individual capture histories of all fish sampled and tagged on the spawning grounds. We then estimated the spawning population size with an open population (Jolly-Seber) model (Schwarz et al. 1993; Pollock et al. 1990). Individual capture histories also allowed us to answer questions about fish movement between major spawning areas and timing of spawning compared to entry into the lake.

In 2004, we continued to estimate certain measures of productivity in the freshwater habitat of Falls Lake. Since 2001, our assessments have included estimates of sockeye fry and smolt populations, zooplankton populations, and profiles of water column light, temperature, and dissolved oxygen (Conitz et al. 2002; Conitz and Cartwright 2003; Conitz and Cartwright 2005). Because of the difficulties in estimating proportions of small fish by species in Falls Lake, we discontinued further attempts to estimate sockeye fry populations in Falls Lake after 2002 (Conitz and Cartwright 2005). However, we continued to estimate the age composition of emigrating smolt populations and in 2004 we attempted to estimate an expansion factor (trap efficiency) that would allow us to estimate the total population of emigrating smolt. In 2004 we continued sampling to estimate zooplankton population characteristics for a tenth year (including six years in the 1980s). These zooplankton estimates give us some indication of the potential sockeye rearing capacity in Falls Lake (Mazumder and Edmundson 2002), and any trends over the long term. We also continued to monitor physical conditions in Falls Lake including water column light, temperature, and dissolved oxygen profiles.

OBJECTIVES

1. Estimate the age, sex, and size composition of outmigrant sockeye smolt at Falls Lake so that the estimated coefficient of variation is less than 10%.
2. Estimate the escapement of sockeye salmon into Falls Lake with mark-recapture studies, marking fish at a trap on the outlet falls and sampling for marked fish on the spawning grounds, so that the estimated coefficient of variation is less than 15%.
3. Estimate the size of the Falls Lake sockeye spawning population within a defined study area on spawning grounds, so that the estimated coefficient of variation is less than 15%. Use observer counts to determine the proportion of the total spawning population that was available for sampling in the study area, and expand the study area estimate to a rough population estimate for the whole lake.
4. Estimate the age, length, and sex composition of the sockeye salmon in the escapement at Falls Lake, based on a sample size of 600, so that the estimated coefficient of variation for the two major age classes is 10% or less.
5. Estimate the subsistence harvest of sockeye salmon from the Falls Lake terminal area, so that the estimated coefficient of variation is less than 15%.
6. Measure light and temperature profiles and estimate zooplankton species composition, size, and abundance in Falls Lake throughout the season using established ADF&G limnological sampling procedures.

METHODS

STUDY SITE

Falls Lake (lat 56°49.5’N, long 134°42.2’W) is located on the east side of Baranof Island (Figure 1), just south of Red Bluff Bay and within the central Baranof metasediments subsection (Nowacki et al. 2001). It lies in a steep mountain cirque basin at an elevation of about 20 m, and drains a watershed area of about 1,650 km^2. The continental ice sheets of the Pleistocene Ice Age never overrode the upper elevations of the steep angular mountains in this area, but abundant precipitation formed smaller alpine glaciers, which carved the landscape and persist today. Frequent landslides, debris torrents, and avalanches sweep down the steep slopes, forming colluvial and alluvial fans around the bases of the mountains (Nowacki et al. 2001).

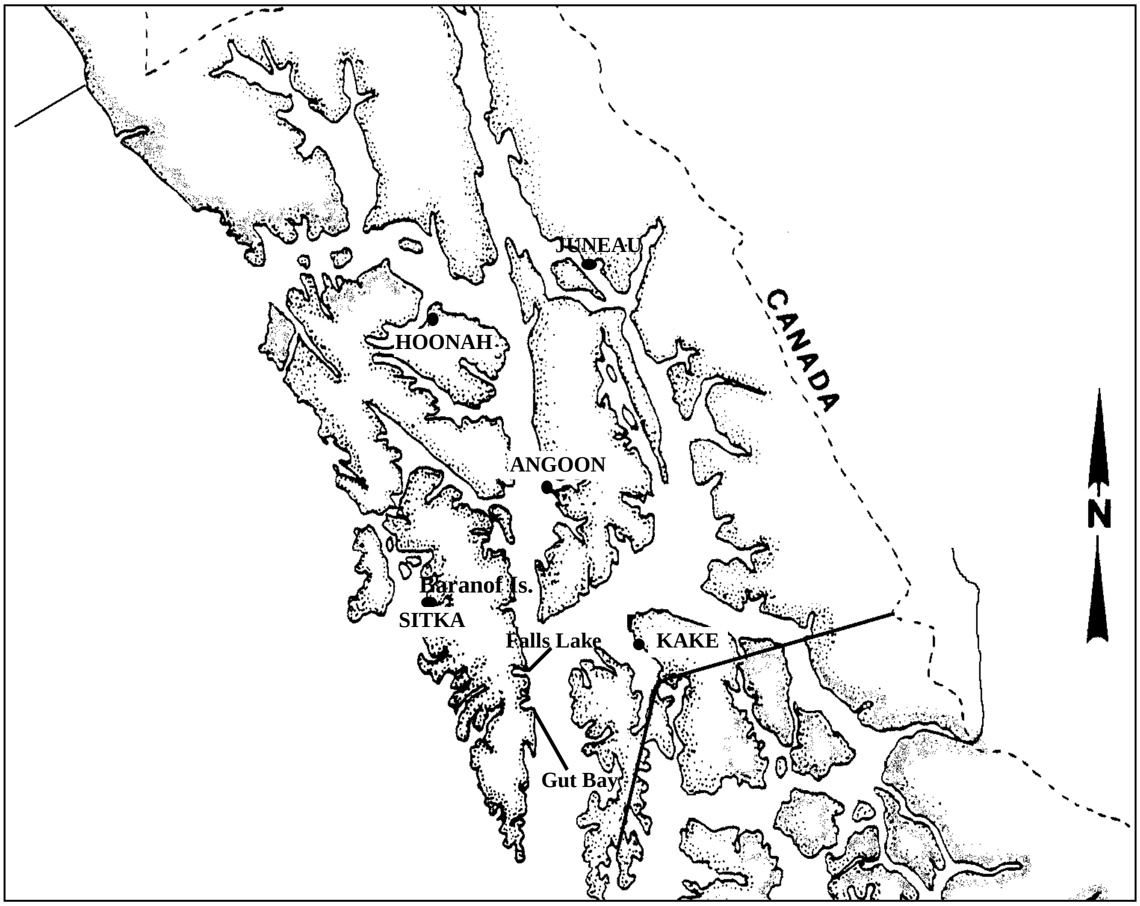

Figure 1.–Map showing the location of Falls Lake on Baranof Island, in relation to the village of Kake, and the larger Southeast Alaska communities of Sitka and Juneau.

Falls Lake's two main inlet streams, originating in hanging glaciers and steep mountain falls, formed large alluvial fans at their lower ends, supporting productive old-growth spruce forest and willow and alder thickets. The southwest inlet stream is sometimes cloudy with glacial silt; the west-southwest inlet stream is usually clear. Both stream channels are dynamic, with rapid changes apparent from flooding, beaver activity, and forest succession. Falls Lake has a surface area of about 95 ha, an average depth of 32 m. The large main basin in the center of the lake reaches a maximum depth of 75 m is separated by a shallow sill from a smaller and shallower basin near the outlet (Figure 2). A very short outlet stream plunges over two falls directly into Chatham Strait. Falls Lake is organically stained and oligotrophic. Nutrient and chlorophyll levels, measured in the 1980s, were low and levels of dissolved ions and other water chemistry parameters were typical of lakes along the southeast Alaska coast (Conitz et al. 2002). Sockeye (*Oncorhychus nerka*) and coho (*O. kisutch*) salmon ascend the falls and spawn in the lake or inlet streams, mainly in the lower reaches and around the mouths of two largest streams entering the southwest corner of the lake. Both streams originate in hanging glaciers and high cirque basins above the lake, and have partial or complete migration barriers a short distance upstream from the lake. Pink salmon (*O. gorbuscha*) spawn in lower section of the outlet stream, but most eggs are probably washed out because suitable gravel is lacking and flow is periodically high; a very small number of pink salmon ascend the falls. The lake supports resident and anadromous populations of Dolly Varden char (*Salvelinus malma*), as well as sticklebacks (*Gasterosteus aculeatus*), and a few sculpins (*Cottus cognatus*). A fishpass was constructed in the upper part of the outlet stream in 1986 by the U.S. Forest Service to aid salmon migration. Mark-recapture study areas centered around the two main inlet streams at the southwest corner of the lake, and limnology sampling stations were located at the deepest points of the two main basins of the lake as in previous years (Table 1 and Figure 2).

Table 1.–Latitude and longitude coordinates for mark-recapture study areas and limnology sampling stations in Falls Lake, determined by Global Positioning System (GPS).

Waypoint ID	Description	Latitude	Longitude
FALLS1	Mouth of main inlet stream	56.819217	134.708067
FALLS2	East end, beach study area	56.821783	134.708383
FALLS3	West end, beach study area	56.819367	134.711967
FALLSA	Limnology Station A	56.823250	134.694000
FALLSB	Limnology Station B	56.825067	134.695133

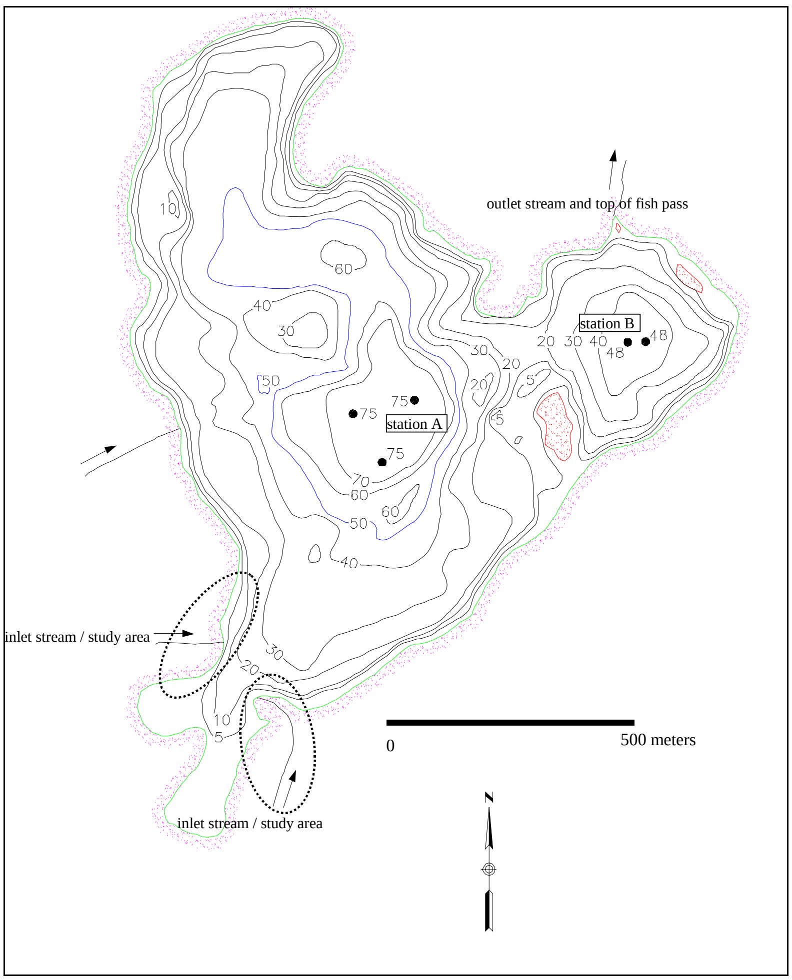

Figure 2.–Bathymetric map of Falls Lake, showing 10 m depth contours, location of trap at top of fishpass on the lake outlet, mark-recapture study areas, and two permanent limnology-sampling stations (A and B).

SOCKEYE SMOLT ESTIMATES

We counted sockeye and coho smolt and sampled sockeye smolt for scales (age), weight, and length during their migration out of Falls Lake from 26 April through 19 June. A fyke net with a 1 m x 1 m frame opening and 10 m side panels was placed in the Falls Lake outlet stream adjacent to the north bank, the same location used in 2003. The open end of the fyke net was about 22 m upstream from the edge of the lower falls, and intercepted a span of about 7 m across the main flow of the stream. The stream channel is approximately 22 m wide at the fyke net location. During trap operation, the cod-end of the net was attached to a live box to hold fish for counting and sampling.

Trap operation began at 2030 hours each evening. We initially operated the trap for three hours each evening, ending at 2330 hours. In order to obtain a more representative count of daily emigration, we increased operation time to four hours per evening starting on 6 May and to six hours per evening starting on 13 May. We operated the trap through three continuous 24-hr days in early May, and through two continuous 24-hr days each subsequent week, to determine if migration followed a consistent diurnal pattern. The crew identified species and counted all fish as they passed them out of the trap with a dip-net. Every effort was made to minimize both holding time and handling.

Each evening, 20–40 sockeye smolt were sampled for age, weight, and length (AWL), depending on total numbers caught in the trap; after mid-May, numbers of migrating smolt declined sharply, and sample sizes were reduced to 20–40 smolt per week. The target sample size for the whole season was 600, enough to distinguish proportions in two or three age classes to a relative precision of 95% (Thompson 1992, p. 39). Smolt for AWL samples were anaesthetized with a clove oil solution (Anderson et al. 1997), weighed to the nearest 0.1 g, and measured to the nearest millimeter; a sample of scales was gently scraped. Smolt were aged by analyzing scale patterns in the laboratory. We estimated mean smolt age, weight, and length compositions from the means of each day's sample, weighted by the mean number of fish per hour counted through the trap each day.

In order to estimate the total population of emigrating smolt in the absence of a full smolt weir, we conducted a pilot study to determine if a mark-recapture estimate would be feasible. We estimated the trap efficiency, or the proportion of emigrating smolt caught in the fyke net trap, during a specific time period. Using a one-site design (Carlson et al. 1998), we marked 150–200 smolt each night (4–5 May and 5–6 May). Smolt were marked by immersing them in a solution of powdered dye (Bismark brown Y) in stream water, at a concentration of 33 mg L^{-1} (Kyle 1983). The solution was kept cold and aerated, and smolt were held in the solution for 20–30 min. Dye-marked smolt were then transferred to a perforated holding pen in the stream and allowed to recover for at least one hour. After the recovery period, the marked smolt were released at the top of the falls above the fyke net trap, between 2300 and 0100 hours each night. Numbers of marked and unmarked fish were counted in the trap continuously throughout the experimental period from 2030 on 4 May until 2330 on 6 May.

We collected fish for marking and mark-recovery samples at the same location, according to the one-site sampling design. The total number of marked smolt, M, was included in the total count, n, of fish sampled in the fyke net trap, and therefore, we needed to estimate only the number of unmarked smolt, U. Specifically, the total number of marked smolt released live in the population, M, was known, so the total population, S, of emigrating smolt could be estimated as the sum of marked and unmarked smolt, $\hat{S} = M + \hat{U}$. We designated *m* as the number of marked smolt recaptured in the fyke net samples and *u* as the number of unmarked smolt in these samples. In the usual Petersen estimate, the total number of mark-recovery samples is the sum of marked and unmarked fish, $m + u$, and is usually designated as *n*. To estimate the total population of unmarked fish during the experimental period, we used a Petersen estimator which only included the unmarked fish in the mark-recovery samples,

$$\hat{U} = \hat{S} - M = \frac{u(M+1)}{m+1}$$ (Carlson et al. 1998).

We estimated the variance of $\hat{U}$ by,

$$v(\hat{U}) = \frac{(M+1)(u+m+1)(M-m)\cdot u}{(m+1)^2(m+2)}$$ (Carlson et al. 1998).

The estimated total population of smolt was simply the sum of the marked and unmarked populations, or $\hat{S} = M + \hat{U}$, and the estimated trap efficiency was the proportion of fish in the total estimated population, $\hat{S}$, that was counted through the trap.

SOCKEYE ESCAPEMENT ESTIMATES

Adult Trap Counts and Mark-Recapture Study

Migrating fish ascending the Falls Lake fish ladder were channeled into a 1.25 m x 1.25 m x 2.5 m box frame trap above the ladder (Conitz et al. 2002). All fish entering the trap were identified by species, counted, and passed upstream. The trap was operated continuously from 20 June through 4 September.

A stratified, two-sample mark-recapture study was used to estimate sockeye salmon escapement into Falls Lake (Arnason et al. 1996). All sockeye salmon passed through the trap were marked with an adipose fin clip and a uniquely-numbered t-bar tag. The adipose clip was considered the primary mark, indicating presence of a tag, and allowing the crew to monitor for tag loss. Following the season, tag numbers applied at the weir were stratified by tagging date into nine strata of one week each.

Six recapture events were conducted on the spawning grounds at approximately ten-day intervals throughout the spawning period. Fish were sampled in the beach spawning area around the inlet stream entering from the west side of the lake, and at the mouth and in the channel of the main inlet stream entering from south of the lake. Tags were applied to all unmarked fish in these samples, and each fish also received an opercular punch to identify the sampling event in which it was caught. A member of the crew recorded tag numbers of all newly captured and recaptured fish, along with sampling date and location. Following the season we compiled tag number data into electronic tables, and used database software to sort tag numbers by sampling event and count sample sizes and numbers of recaptured fish in each sample. Newly captured or recaptured fish were only counted on the first sampling event in which they were encountered. We estimated tag loss in this study by recording recaptures of sockeye salmon with a clipped adipose fin but no tag, and calculating the proportion of such fish in the total number of recaptures. Because all tagged fish were marked with adipose clips, fish with lost tags could still be identified as recaptures and included in the recapture data, although the initial capture strata of such fish were unknown. We apportioned all recaptures of fish with lost tags to initial capture strata based on proportions of all fish marked at the trap in each stratum.

The two-sample Petersen method is a simplistic model for estimating total escapement based on the total number of fish marked as they move into the lake (first sample), the total number of fish subsequently sampled for marks on the spawning grounds (second sample), and the number of marks recovered in the second sample (Seber 1982, p. 59; Pollock et al. 1990). Stratified mark-recapture models extend the two-sample Petersen method over two or more sampling occasions or events in both the marking (first) and mark-recovery (second) samples. Stratified models are widely used for estimating escapement of salmonids as they migrate into their spawning streams (Arnason et al. 1996). Spawning migrations may last for a month or more, during which there can be substantial variation in biological parameters such as daily immigration or mortality rates. A fundamental assumption of the Petersen and related mark-recapture models is that capture probabilities for individual animals are equal (Pollock et al. 1990). The natural variation typical of salmon escapements presents many possibilities for individual capture probabilities to vary, but if certain conditions are met, the simplifying assumptions of equal capture probability can be used. Briefly stated, the three assumptions of equal probability of capture required by the Petersen model are: 1) all fish have an equal probability of capture in the first sample (marking), 2) all fish have an equal probability of capture in the second sample (mark-recovery), and 3) fish mix completely between the first and second sample. Generally, if one or more of these assumptions is met, data from all marking and all mark-recovery samples can be pooled, thereby providing the most precise estimate. However, if none of the assumptions are met, the pooled estimate can be badly biased (Arnason et al. 1996).

We used the Stratified Population Analysis System (SPAS) software to aid in analyzing and interpreting mark-recapture results (Arnason et al. 1996; for details, refer to http://www.cs.umanitoba.ca/~popan/). SPAS calculates Darroch and "pooled Petersen" estimates, and provides two goodness-of-fit tests to compare observed and expected capture probabilities in the marking (first) and mark-recovery (second) samples (Arnason et al. 1996). The test of the assumption of complete mixing is incorporated into the test for equal probability of capture in the second sample. A test statistic with p-value ≤ 0.05 was considered significant, and prompted us to further examine the data and alternate stratification schemes. We looked at sample sizes and capture probabilities in each marking and mark-recovery stratum, and considered any problems with or failures to follow the sampling design. We then checked the Darroch estimate for possible problems, such as a failure of the SPAS program to converge on a solution, or an estimate much larger or smaller than the pooled Petersen estimate. Depending on the nature of the problems, we searched for a partial pooling scheme that more closely fit actual sampling conditions, and we followed the guidelines and suggestions in Arnason et al. (1996) to help decide between the pooled Petersen or Darroch estimate.

When use of the pooled Petersen method was warranted, we used the following alternative method to estimate the 95% confidence interval for the escapement estimate, rather than the method provided in the SPAS software. We let K denote the number of fish marked in a random sample of a population of size N. We let C denote the number of fish examined for marks at a later time, and let R denote the number of fish in the second sample with a mark. The estimated number of fish in the entire population, $\hat{N}$, was calculated by,

$$\hat{N} = \frac{(K+1)(C+1)}{(R+1)} - 1.$$

In this equation, R was the random variable, and C and K were assumed to be constants. With moderate or large numbers of mark-recoveries, which is generally the case if the pooled Petersen estimate met the criteria outlined above, the distribution for R can be approximated with the normal distribution. We let $\hat{p}$ be an estimate of the proportion of marked fish in the population, p, such that $\hat{p} = \frac{R}{C}$. When sample sizes and number of marks recovered were adequate according to the criteria in Seber (1982, p. 63–64), we constructed a confidence interval for p using the normal approximation,

$$\hat{p} \pm \left[1.96\sqrt{\left(1-\frac{C}{\hat{N}}\right)\cdot \hat{p}(1-\hat{p})/(C-1)} + \frac{1}{2C}\right]$$ (Seber 1982, eq. 3.4).

Otherwise, we found confidence interval bounds for p using Table 41 in Pearson and Hartley (1966). We defined the confidence bounds for p as ($a_{0.025}$, $a_{0.975}$). Then we constructed the 95% confidence interval bounds for population, N, by taking reciprocals of the confidence interval bounds for p, and multiplying by K,

$$\left(K \cdot 1/a_{0.975},\ K \cdot 1/a_{0.025}\right).$$

Spawning Grounds Mark-Recapture Study and Visual Surveys

We wanted to determine if we could obtain a reliable estimate of escapement by sampling only on the spawning grounds in the fall, in lieu of counting and sampling sockeye salmon as they entered the lake throughout the season. Using the Jolly-Seber model for open populations (Pollock et al. 1990), with an adjustment for spawning salmon populations (Schwarz et al. 1993), we estimated the number of sockeye spawners on the spawning grounds in Falls Lake. The crew sampled fish in established study areas with a beach seine and a small barrier net in the stream channel. Sampling began as soon as sockeye salmon moved into the spawning areas, and a second event followed a few days after the first such that mortality would be at or near zero between these two events. We then sampled at approximately ten-day intervals until the number of available spawners declined and it was apparent that few or no new fish were entering the spawning areas. Tags were applied to all unmarked fish in these samples, with an opercular punch to identify the sampling event in which the fish was caught. Fish that had already been tagged at the weir were treated as if they were tagged on the first sampling event in which they were encountered on the spawning grounds. A crew member recorded tag numbers of all newly-marked and previously-marked fish, along with sampling date and location.

Following the season we compiled tag number data into electronic tables, and used database software to sort tag numbers by sampling event. We constructed an individual capture history for each fish, denoting a sampling event in which the fish was captured with a "1" and a sampling event in which the fish was not captured with a "0" (Pollock et al. 1990). From capture histories of fish with multiple recaptures, we were also able to look for incidence of spawners moving between different spawning areas. For fish with lost tags, we could reconstruct capture histories up to the most recent recapture by noting patterns of primary opercular punch marks or fin clips.

If a particular pattern of primary marks with a lost tag was not seen in a later recapture, we could assume no more recaptures of that fish and complete its capture history with zeros for all subsequent sampling events. Each fish with a lost tag was also associated with an apparent capture history, consisting of a capture (1) in the event prior to the event in which the lost tag was noted, with no recaptures (all zeros) for subsequent events. If we were able to reconstruct and add a capture history for a fish with a lost tag, we also deleted the apparent capture history.

Data Analysis

The Jolly-Seber model extends the Schnabel method (Seber 1982, p. 130) to open populations. Population size is estimated at the time of each sample, and the number of new animals entering the population is estimated between sampling events, for s sampling events. In using this model we must assume:

1. Every fish present in the population at time of the ith sampling event (i=1, 2, …, s) has the same probability of capture (p_i)
2. Every fish (marked and unmarked) present in the population immediately after the ith sampling event has the same probability of survival (ϕ_i) until the (i+1 th) sampling event (i = 1, 2,…, s-1).
3. Marks are not lost or overlooked.
4. Sampling time is negligible.

We designated the following parameters:

N = size of "super population," or escapement;

M_i = number of marked fish in the population at time of the ith sampling event (i=1, 2, …, s; M_1=0);

N_i = total number of fish in the population at time of the ith sampling event (i=1, 2, …, s; N_1=B_0);

B_i = total number of new fish entering the population before the first event, and between the ith event and (i+1th) event, and still in the population at time of (i+1th) event (i=0, 1, …, s-1). B_0 is the number of fish that entered the population before the first event and are still alive at the time of the first event;

ϕ_i = survival probability for all fish between the i^{th} event and (i+1th) event (i=1, 2, …, s-1).

We also designated the following statistics:

m_i = number of marked fish captured in the i^{th} event (i=1, 2, …, s);

u_i = number of unmarked fish captured in the i^{th} event (i=1, 2, …, s);

n_i = $m_i + u_i$, total number of fish captured in the i^{th} event (i=1, 2, …, s);

R_i = number of the n_i fish that are released after the i^{th} event (i=1, 2, …, s-1). This may not be all of n_i fish due to losses on capture;

r_i = number of R_i fish released at i and captured again (i=1, 2, …, s-1);

z_i = number of fish captured before i, not captured at i, and captured again later (i=2, …, s-1).

The following unbiased estimators were recommended by Seber (1982:204):

$$\hat{M}_i = m_i + \frac{(R_i + 1)z_i}{r_i + 1};$$

$$\hat{N}_i = \frac{(n_i + 1)\hat{M}_i}{m_i + 1};$$

$$\hat{\phi}_i = \frac{\hat{M}_{i+1}}{\hat{M}_i - m_i + R_i};$$

$$\hat{B}_i = \hat{N}_{i+1} - \hat{\phi}_i(\hat{N}_i - n_i + R_i).$$

Seber (1982:204) recommended that m_i and r_i should be greater than 10 for satisfactory performance of these bias-adjusted estimators.

We assumed the interval between the last (s^{th}) sampling event, and the next-to-last (s-1^{th}) sampling event was so short that the number of fish entering the population during this interval was negligible. Furthermore, we assumed that sampling extended to a time when immigration had ended, and the number of fish entering the population was negligible. Escapement can be estimated as the sum of all $\hat{B}_i$, estimated numbers of fish that entered the population between sampling events. However, each $\hat{B}_i$ is the number of fish that entered the population after sampling event i and were alive at sampling event i+1. These estimates exclude those fish in the escapement that entered after sampling event i but died before sampling event i+1. Consequently, Jolly-Seber estimates of B_i underestimate spawning recruitment, except when all fish are known to survive from their entry to the next sampling event. To account for those fish that entered the system after sampling event i but died before sampling event i+1, we adjusted $\hat{B}_i$ by a probability distribution approach (Schwarz 1993). Let B_i^* denote the total number of new fish entering the population between sampling events (including those that died before the next sampling event). When recruitment and mortality are assumed to occur uniformly between sampling events, the maximum likelihood estimator (MLE) for B_i^* is

$$\hat{B}_i^* = \hat{B}_i \frac{\log(\hat{\phi}_i)}{\hat{\phi}_i - 1}.$$

$\hat{B}_0$, $\hat{B}_1$, and $\hat{B}_{s-1}$ are confounded parameters and cannot be estimated without further assumptions (Schwarz et al. 1993). However, we assume recruitment had virtually ended before the last sampling event, so we set $\hat{B}_{s-1}$ to zero. The number of fish alive in the population on the second sampling event, N_2, can be estimated as,

$$\hat{N}_2 = \hat{B}_0\phi_1 + \hat{B}_1.$$

So a reasonable estimate of the number of fish that entered the system before the first sampling event and between the first and second sampling events, including those that entered the system and died before and between these sampling events, is,

$\hat{N}_2 \dfrac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1}$ (Schwarz et al. 1993).

We then estimate the super population, or total escapement, as

$$\hat{N} = \hat{N}_2 \frac{\log(\hat{\phi}_1)}{\hat{\phi}_1 - 1} + \sum_{i=2}^{s-1} \hat{B}_i^* .$$

We used a non-parametric bootstrap technique to estimate variance and form a confidence interval for *N*. Using a program written in S-Plus (MathSoft 1999; X. Zhang, ADF&G Division of Commercial Fisheries, unpublished document 2005), we resampled the observed experimental data to create a series of "pseudo-experiments," according to the following algorithm:

1. Analyze observed data using the Jolly-Seber method and Schwarz's adjustment described above to obtain the $\hat{N}$.
2. Sample with replacement from the observed *n* capture histories to generate a bootstrap sample of same size *n*; analyze the bootstrap sample exactly as if it were the observed sample.
3. Repeat step (2) for 1000 bootstrap samples to have 1000 estimates of *N* from these bootstrap samples.
4. Calculate variance and standard error for $\hat{N}$ from the 1000 bootstrap estimates of *N*.
5. Estimate the 95% confidence interval by taking the 0.025 and 0.975 quantiles of the 1000 bootstrap estimates of *N*.

Visual Surveys

Mark-recapture sampling was conducted in specific places, designated as the study area (Table 1 and Figure 2), within the main spawning areas of the Falls Lake system. Consequently, spawning population estimates apply only to the portion of the total spawning population that could be sampled within the designated study area. To determine the proportion of the total spawning population available for sampling in the study area, we estimated the total number of sockeye spawners in the lake and the number of spawners within the study area using visual survey counts. Just before each sampling event, at least three observers counted sockeye spawners from a skiff motoring slowly around the lake perimeter, and on foot walking up the spawning streams. The survey encompassed the entire lake and each inlet stream to the upper extent that fish have been observed. Fish in the study area were counted separately. After each survey, we divided the mean count (between all observers) for the study area by the mean count for the whole lake (including streams), to estimate the proportion of fish within the study area at that sampling event. The proportion of fish in the study area over the entire season was estimated by taking the mean of proportions in the study area at each sampling event, weighted by the estimated spawning population size at each event.

Adult Population Age and Size Distribution

About 600 length, sex, and scale samples were collected from adult sockeye salmon at the Falls Lake trap to estimate the size, sex, and age structure of the population. Fish were selected systematically (e.g. every fifth fish) to prevent selection bias, throughout the entire run. Length of each fish was measured from mid eye to tail fork, to the nearest millimeter (mm). Sex of the fish was decided by length and shape of the kype or jaw. Three scales were taken from the preferred area of each fish (INPFC 1963), and prepared for analysis as described by Clutter and Whitesel (1956). Scale samples were analyzed at the ADF&G salmon aging laboratory in Douglas, Alaska. Age classes were designated by the European aging system where freshwater and saltwater years are separated by a period (e.g. 1.3 denotes a five-year-old fish with one freshwater and three ocean years; Koo 1962). The weekly proportion in each age class, and the mean weekly proportion in each age-sex group weighted by total trap count per week, were estimated. Associated standard error was estimated using standard statistical techniques and assuming a binominal distribution (e.g. Thompson 1992). Mean lengths by age and sex were likewise estimated from weekly means weighted by the total trap count per week.

HARVEST ESTIMATE

As in 2003, subsistence fishing was open at Falls Lake from 1 June through 20 July, with a mid-season closure from 7–14 July. Subsistence fishing reopened at Falls Lake from 19–31 August in response to an unfortunate situation in which a bad batch of canning jar lids resulted in widespread spoilage of preserved subsistence fish. Sport fishing was open the entire season from May through September.

Given the low number of participants in the fishery, samplers were able to monitor the fishing area during the entire sampling period from 0500 to 2300 daily, between 1 June and 31 August. Both subsistence and sport fisheries were monitored. Fishery participants were contacted as they entered the area, counted by gear type (subsistence seine, subsistence gillnet, or sport rod), and asked to complete an interview before leaving the area. Data collected during each interview included angler effort (rod or net hours) and harvest by species. If the technician was unable to interview a party because two or more boats were leaving at the same time, one boat was randomly selected using a coin toss. The boat-party not selected, or any boat-party the crew was unable to interview for other reasons, was recorded as a missed interview.

Equations for estimating harvest, catch, and effort in each harvest survey were those for a one-stage direct expansion (access point, completed-trip interview) survey (Cochran 1977). This design was appropriate because the crew could accurately count all participating boat-parties and interview most after they completed fishing. The primary sampling units were boat-parties within days. We let h_{jg} denote harvest on boat j using gear g, m_g denote number of boat parties interviewed using gear g, and M_g denote number of boat-parties counted using gear g. The harvest, of each species by gear group g, was estimated as,

$$\hat{H}_g = \frac{M_g}{m_g} \sum_{j=1}^{m_g} h_{jg} \ .$$

Letting $\bar{h}_g$ denote the mean harvest per boat for the g^{th} gear group, the variance of the harvest by stratum was estimated as,

$$\text{var}(\hat{H}_g) = (1 - \frac{m_g}{M_g}) M_g^2 \frac{\sum_{j=1}^{m_g} (h_{jg} - \bar{h}_g)^2}{m_g (m_g - 1)} .$$

If all boat-parties in a gear group were interviewed, the one-stage design collapsed into a complete census, and we estimated harvest of each species by simply summing the harvests reported by all the boat-parties. The total harvest estimate for the season was the sum of harvests for all gear groups, and estimated variance of the total harvest estimate was the sum of variances for all gear groups. The coefficient of variation (CV) for each estimate was the square root of the variance divided by the estimate.

LIMNOLOGY SAMPLING

Limnology sampling was conducted on four dates in Falls Lake in 2004, beginning in early May and repeated at approximately six-week intervals through late September. Light and temperature measurements were taken only at Station A. Zooplankton samples were collected from two stations (A and B; Figure 2) on each sampling date (Conitz et al. 2002). We reported estimates as between-station averages.

Light and Temperature Profiles

Underwater light intensity was recorded from just below the surface to the depth where measured intensity was one percent of the surface light reading, at 0.5 m intervals, using an electronic light sensor and meter (Protomatic). The natural log (ln) of the ratio of light intensity just below the surface to light intensity at depth z (I_0/I_z) was calculated for each depth. The vertical light extinction coefficient (K_d) was estimated as the slope of $\ln(I_0/I_z)$ versus depth. The euphotic zone depth (EZD) was defined as the depth at which light intensity was reduced to one percent of the value just below the surface [photosynthetically available radiation (400–700nm)] (Schindler 1971), and was calculated from the equation, EZD = 4.6205/ K_d (Kirk 1994).

Temperature, in degrees centigrade (ºC) was measured with a Yellow Springs Instruments (YSI) Model 58 meter and probe. Measurements were made at one-meter intervals to the first 10 m or the lower boundary of the thermocline (defined as the depth at which the change in temperature decreased to less than 1ºC per meter). Below this depth, measurements were made at five-meter intervals to 50 m.

Secondary Production

Zooplankton samples were collected at two stations using a 0.5 m diameter, 153 µm mesh, 1:3 conical net. Vertical zooplankton tows were pulled from 50 m at station A, and two meters from the bottom at station B, at a constant speed of 0.5 m sec^{-1}. The net was rinsed prior to removing the organisms, and all specimens were preserved in neutralized 10% formalin (Koenings et al. 1987). Each zooplankton tow was sub-sampled in the laboratory, and technicians identified to species or genus, counted, and measured organisms in the sub-samples (Koenings et al. 1987). Density (individuals per m^2 surface area) was extrapolated from counts by taxon in the sub-samples, and seasonal mean density was estimated by taking the simple average of densities across sampling dates. The seasonal mean length for each taxon, weighted by density at each sampling date, was estimated and used to calculate a seasonal mean biomass estimate (weight per m^2 surface area) based on known length-weight relationships (Koenings et al. 1987). Total seasonal mean zooplankton biomass and density were estimated by summing across all species.

RESULTS

SOCKEYE SMOLT ESTIMATES

Totals of 6,869 sockeye smolt, 449 coho smolt, 139 Dolly Varden char, 27 sticklebacks, and 6 sculpins were counted through the smolt trap in 462 total hours of trap operation between 26 April and 19 June, 2005 (Appendix A). Peak numbers of emigrating sockeye smolt were counted between about 2 and 12 May (Figure 3). The maximum count was 1,131 sockeye smolt on 11 May, during one 24-hour cycle of continuous trap operation (11 May 2030 hours through 12 May 2030 hours). The proportion of total daily smolt emigration sampled in an average six-hour period of trap operation (2030–0230 hours) was extremely variable, based on nine periods of continuous 24-hour sampling (Table 2).

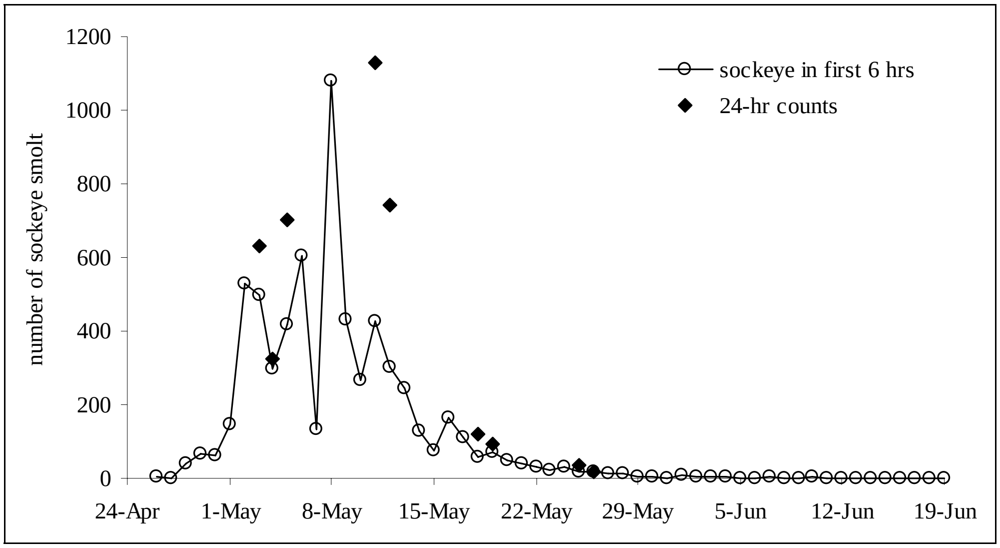

Figure 3.–Daily counts of sockeye smolt through a fyke-net trap in Falls Lake outlet stream, 2004. The solid line and open points show daily counts of smolt for the first six hours of each 24-hr period, beginning at 2030 hours and ending at 0230 hours. Six-hour counts were extrapolated from three-hour counts for 26 April–2 May and from four-hour counts for 6–10 May. On all other dates, actual counts are shown. Filled points show total counts from 24-hour trap operations on 2–3 days per week in May.

Table 2.–Percentages of total daily emigration of Falls Lake sockeye smolt counted in the first four, six, and twelve hours of trap operation, beginning at 2030 hours each evening. Sockeye smolt were counted for two or three consecutive 24-hr periods, once a week in May 2004.

Week	Date	Percent of 24-hour total counted through trap after:			Total count
		4 hours	**6 hours**	**12 hours**	
1	3-May	46%	79%	93%	631
	4-May	74%	92%	100%	326
	5-May	36%	60%	70%	701
2	11-May	23%	38%	46%	1,131
	12-May	13%	41%	84%	743
3	18-May	31%	48%	60%	120
	19-May	43%	77%	82%	92
4	25-May	37%	46%	71%	35
	26-May	26%	89%	89%	19

To estimate trap efficiency, we released a total of 340 marked sockeye smolt between 0000 and 0100 hours on 5 and 6 May. We held 35 marked smolt for two days to assess short-term mortality and mark loss. Six marked smolt died, but marking remained visible on all. The estimated mark-survival rate was 83%, and we adjusted the number of smolt marked and released by this factor (Table 3). Nearly all recaptures of marked smolt occurred within the first one or two hours following release. From numbers of marked and unmarked smolt caught in the fyke net during the 51-hr sampling period (Table 3), we estimated a total of about 1,500 unmarked smolt (CV=5%), and a total population of about 1,800 smolt (CV=4%). The trap efficiency, or percentage of the estimated total smolt population that was caught in the fyke net, was 57%.

We judged the mortalities of marked fish to be unacceptably high in terms of our handling effects on the overall sockeye population. For this reason, and because we did not have confidence that marked and unmarked smolt could mix thoroughly in the short and very turbulent section of stream between lake outlet and fyke net, we discontinued mark-recapture experiments.

Table 3.–Numbers of sockeye smolt marked and released at the falls and sampled in the fyke net trap below the falls, in a one-site mark-recapture experiment. Experimental periods were 4 May 2030 hours to 5 May 2030 hours and 5 May 2030 hours to 6 May 2330 hours, 2004.

Numbers of sockeye smolt:	4–5 May	5-6 May	Totals
marked and released	151	131	282
recaptured with mark	114	73	187
unmarked, captured in trap	212	628	840
total, captured in trap	326	701	1,027
mortalities in trap	16	1	17

We sampled 653 sockeye smolt from the 6,869 smolt counted through the fyke-net trap between 26 April and 19 June. Ages were determined from the scales of all but one of these samples. The estimated age composition, weighted by mean hourly smolt count each day, was about 75% age-1 smolt and 25% age-2 smolt, with a standard error of 2% for each proportion (CV=3% for the larger proportion). Age-2 smolt were about 0.6 g heavier and about 4 mm longer, on average, than age-1 smolt (Table 4).

Table 4.–Mean weights and lengths by age of sockeye smolt emigrating from Falls Lake in 2004. Means were weighted by the mean smolt count per hour of sampling each evening.

Age class	Age 1	Age 2
Mean weight (g)	3.70	4.27
CV (mean weight)	0.6%	0.8%
Mean length (mm)	80	84
CV (mean length)	0.2%	0.2%

SOCKEYE ESCAPEMENT ESTIMATES

Adult Trap Counts and Mark-Recapture Study

Between 20 June and 4 September 2004, we counted 1,640 adult sockeye salmon through the trap at the top of the Falls Lake fish ladder (Appendix B). The crew marked all but one of these fish with adipose clips and uniquely-numbered tags. Other fish counted through the trap included 120 coho salmon, one Chinook salmon, and nine Dolly Varden char (Appendix B). We are confident that our trap operation period bracketed the entire period of sockeye escapement into the lake, but not necessarily the escapement periods of other species. Although the first two sockeye salmon moved up the fish ladder on 26 June, no other sockeye salmon were counted in the trap between 20 June and 7 July. Substantial movement of sockeye salmon into the lake began in late July. The peak escapement period was five days at the beginning of August, with the highest daily count of 223 sockeye salmon on 3 August. Sockeye escapement persisted in small numbers through the last date of trap operation on 4 September (Appendix B).

To estimate total sockeye escapement into Falls Lake, we stratified the 1,639 tagged fish into marking periods of one week each, and sampled 1,278 fish in three main sampling locations (beach study area, mouth of main inlet stream, and channel of main inlet stream). We also examined probabilities of recapture by time of marking and location of recapture (Table 5). No relationship was apparent between time of entry into the lake (week when tagged) and eventual spawning location. Roughly equal proportions of tagged fish were recaptured at each of the three main sampling locations. Consistency of capture probabilities among recapture strata (the three sampling locations) was reflected in a non-significant chi-square test value for "equal proportions" in SPAS (X^2=0.99, p-value=0.61, 2 df). However, recoveries of tagged fish from each marking stratum varied significantly, as reflected in a significant chi-square test value for "complete mixing" (X^2=28, p-value<0.001, 8 df). The Darroch and the pooled Petersen estimate were about the same, within the limits of precision for each estimate. Therefore, we concluded that there was insufficient evidence of bias to reject the pooled Petersen mark-recapture estimate, and we used the pooled Petersen estimate of 3,300 sockeye salmon (CV=2%). The estimated 95% confidence interval was 3,200–3,500 sockeye salmon.

Table 5.–Numbers of sockeye salmon marked at the trap per week and numbers of recaptures by week and location, at Falls Lake, 2004. Total numbers and proportions of mark-recoveries by week of marking at the trap, and total sample sizes and proportions of recaptures in each recapture stratum (location) are also shown.

		Recapture strata (location)			All mark recoveries, by marking stratum	
Marking stratum (week)	**Number marked**	**Beach**	**Mouth of stream**	**Stream**	**Number**	**Proportion**
28	2	1	0	0	1	0.50
29	201	24	18	41	83	0.41
30	245	37	24	30	91	0.37
31	220	32	30	30	92	0.41
32	610	102	91	58	251	0.41
33	105	10	15	11	36	0.34
34	170	20	26	15	61	0.35
35	46	3	4	2	9	0.20
36	40	0	3	0	3	0.08
Totals	1,639	229	211	187	627	
Total sampled		481	414	383	1,278	
Proportion of marked fish in recapture samples		0.47	0.51	0.49		

We also examined capture probabilities and probabilities of recapture by time of marking and time of recapture (Table 6). Roughly equal proportions of tagged fish were recaptured at each sampling occasion and the chi-square value for "equal proportions" was non-significant (X^2=5.52, *p*-value=0.36, 5 df). The marking strata and numbers of recaptures from each were the same as in the previous stratification scheme, and so results for the "complete mixing" test in SPAS were unchanged (X^2=28, *p*-value<0.001, 8 df). Initially, the SPAS program did not converge on a solution for the Darroch estimate, but if marking strata were pooled by grouping weeks with similar recapture proportions (weeks 28–32 and weeks 33–36), a solution was found. The Darroch estimate was the same (3,300; CV=3%) as when recaptures were pooled by location, and the same as the pooled Petersen estimate, within the limits of precision for each estimate. A weak diagonal pattern appears in the recapture matrix (Table 6), indicating a positive relationship between date of entry into the lake (marking stratum) and date of appearance on the spawning grounds (recapture event). However, the pattern appears to be inconsistent and dominated by larger sample sizes and recapture numbers in the earlier strata (both marking and recapture).

Table 6.–Numbers of fish marked and recaptured and sample sizes by week of marking at the trap and date of recapture event on the spawning grounds at Falls Lake 2004. The broken line below week 32 indicates pooling of weeks 28–32 and 33–36 for analysis with program SPAS.

Marking stratum (week)	Number marked	Recapture event						All recaps	Proportion recaptured by marking stratum
		20 Aug	24 Aug	2 Sep	14 Sep	24 Sep	29 Sep		
28	2	0	1	0	0	0	0	1	0.50
29	201	38	26	10	5	3	1	83	0.41
30	245	39	20	18	10	4	0	91	0.37
31	220	36	18	20	11	6	1	92	0.42
32	610	78	48	68	37	13	7	251	0.41
33	105	7	5	11	8	3	2	36	0.34
34	170	10	4	20	17	7	3	61	0.35
35	46	0	1	4	4	0	0	9	0.20
36	40	0	0	2	1	0	0	3	0.08
Totals	1,639	208	123	153	93	36	14	627	
Total sampled		449	262	290	183	72	22		
Proportion of marked fish in recapture samples		0.46	0.47	0.53	0.50	0.50	0.64		

Out of 627 marked fish recaptured on the spawning grounds, 21 tags were lost. Because these fish had adipose fin clips, we were able to include them directly in the analysis. Because the date of tagging was unknown if the tag was lost, we apportioned recaptures of fish with lost tags among marking strata in proportion to numbers marked each week.

Spawning Grounds Mark-Recapture Study and Visual Surveys

To independently estimate escapement of sockeye spawners in Falls Lake, we sampled 1,239 fish within the designated study area on the spawning grounds in 2004. The sampling dates were 20 and 24 August and 2, 14, 24, and 29 September. Using the Jolly-Seber model, we estimated a spawning population within the study area of about 2,600 sockeye salmon (95% confidence interval 2,400–2,900; CV=5%). About 27% (338 fish) of all fish sampled were captured in more than one sampling event (Table 7). The high number of recaptures contributed to good precision of the mark-recapture estimate. Nearly 12% (146 fish) were caught after two or more periods between sampling events, including 58 multiple recaptures (Table 7). The longer elapsed time between recaptures and the number of multiple recaptures indicate sockeye salmon have a residence time of two weeks or more on the Falls Lake spawning grounds.

Table 7.–Summary of capture-recapture histories of sockeye salmon sampled on the Falls Lake spawning grounds, 2004. The capture history for each fish consists of a “1” for a sampling event in which the fish was caught and released, and a “0” for a sampling event in which the fish was not caught. The six sampling events are represented in consecutive order in each capture history. The number of fish with each observed capture history, and the total number in each category, are shown.

Capture-recapture category	Capture history	Number of fish
Captured only once	100000	290
	010000	210
	001000	199
	000100	143
	000010	44
	000001	15
Subtotal		901
Recaptured at next event	110000	84
	001100	42
	011000	33
	000011	18
	000110	15
Subtotal		192
Recaptured after next event	101000	34
	100100	12
	010100	11
	001001	10
	000101	9
	001010	8
	100010	2
	100001	2
Subtotal		88
Recaptured more than once	111000	15
	001110	7
	001111	6
	001011	6
	110100	4
	111100	3
	101100	3
	011100	3
	001101	3
	000111	2
	110001	1
	101011	1
	101010	1
	100110	1
	011110	1
	011011	1
Subtotal		58
	Total	1,239

Based on the visual survey counts, the proportion of sockeye spawners in the study area compared to all spawners in Falls Lake varied from 0.80 to 0.93 (Table 8). The average proportion in the study area, weighted by abundance at each sampling date (whole lake count), was 0.87 for the entire spawning period. Adjusting our study area estimate (2,600 fish) by this proportion, we obtained a total spawning population estimate of about 3,000 sockeye salmon.

Table 8.–Visual counts of sockeye spawners and proportion of spawners in the study area at each sampling date, in Falls Lake, 2004.

Date	Average count within study area	Average count for whole lake	Proportion in study area
20 Aug	588	631	0.93
24 Aug	778	864	0.90
2 Sep	1,070	1,236	0.87
14 Sep	592	718	0.82
24 Sep	275	326	0.84
28 Sep	151	188	0.80

The estimate of total spawning population was less than the pooled Petersen estimate (3,300 fish) based on fish marked at the trap. However, because the closure assumption was relaxed to allow death, the Petersen estimate applies to the population at time of first sample, i.e. the number of fish entering the lake (Pollock et al. 1990). The estimate on the spawning grounds represents only the actual spawning population and would be less than the number entering the lake if there is some natural mortality before spawning begins.

We examined the tag number data for frequency of movement of fish between the three main sampling locations (beach study area and mouth and channel of main inlet stream). We expected fish to move from the mouth into the channel of the main inlet stream because these fish usually spawn in the stream channel rather than at the mouth, and this was confirmed by recapture locations and timing. Additionally, at least 61 fish out of 338 fish caught more than once on the spawning grounds, or about 18%, moved between the beach study area and the mouth or channel of the main inlet stream. Because fish appear to migrate between spawning locations, it may be more appropriate to pool data from all locations than to produce a separate estimate for each area as we did in previous years.

In sampling on the spawning grounds, 49 fish were captured or recaptured with lost tags. We were able to reconstruct actual and apparent capture histories for 37 of these fish, and included these in the analysis. Capture histories could not be unambiguously reconstructed from the remaining 12 lost tag records, representing an uncertainty of about ±1% of total capture histories. Because this source of error was small, we ignored it.

Adult Population Age and Size Distribution

From a total sample of 520 sockeye salmon sampled at the Falls Lake trap, we estimated that about 80% of the sockeye escapement in 2004 were fish that spent one year in Falls Lake as juveniles (Table 9). The sockeye salmon returning to Falls Lake were evenly split between fish with two ocean years and fish with three ocean years. Dominant age classes were 1.3 (CV=5%) and 1.2 (CV=6%). Five-year-old fish (age-1.3 and age-2.2) comprised an estimated 56% of the escapement. The sex ratio was about 40% male to 60% female. As expected, fish that spent three years at sea (age-1.3 and age-2.3) were larger, on average, than their counterparts with two ocean years (Table 10), and more of them returned earlier to Falls Lake. Those fish with three ocean years represented a slightly higher proportion of escapement early in the season (July), but throughout August, fish with two ocean years represented more than 50% of weekly escapement through August (Table 11).

Table 9.–Age composition of adult sockeye salmon in the Falls Lake escapement by sex, 2004. Percentages in each age group were weighted by weekly counts through the trap. Estimated numbers in each age class, based on total estimated escapement (3,300 fish) are also shown.

Brood Year	2000	1999	1999	1998	
Age Class	**1.2**	**1.3**	**2.2**	**2.3**	**All aged**
Male					
Number	59	114	22	19	214
Percent	11.5%	22.4%	3.7%	3.6%	41.2%
SE (%)	1.4%	1.8%	0.9%	0.8%	2.2%
Female					
Number	136	102	53	15	306
Percent	26.1%	20.0%	9.6%	3.1%	58.8%
SE (%)	1.9%	1.7%	1.3%	0.7%	2.2%
All Fish					
Number	195	216	75	34	520
Percent	37.6%	42.4%	13.3%	6.7%	100%
SE (%)	2.1%	2.2%	1.5%	1.1%	
Escapement by age class	1,241	1,399	439	221	3,300

Table 10.–Mean mideye to fork length (mm) of adult sockeye salmon in the Falls Lake escapement, 2004. Mean lengths were weighted by weekly counts through the trap.

Brood Year	2000	1999	1999	1998
Age Class	**1.2**	**1.3**	**2.2**	**2.3**
Male				
Sample Size	59	114	22	19
Average Length (mm)	486	550	503	553
SE (Av Length)	3.6	2.0	5.8	3.5
Female				
Sample Size	136	102	53	15
Average Length (mm)	489	547	497	544
SE (Av Length)	2.2	2.0	2.4	3.7
All Fish				
Sample Size	195	216	75	34
Average Length (mm)	488	549	498	549
SE (Av Length)	1.9	1.4	2.5	2.8

Table 11.–Weekly percentage age composition in the Falls Lake escapement, 2004, based on total number of fish sampled per week.

Week beginning	Percent of weekly total sample, by age class				Number sampled	Number counted in trap
	1.2	1.3	2.2	2.3		
11-Jul	14%	52%	7%	27%	44	200
18-Jul	37%	41%	20%	2%	127	244
25-Jul	30%	46%	18%	6%	84	220
1-Aug	45%	40%	12%	3%	147	611
8-Aug	39%	34%	14%	13%	64	106
15-Aug	44%	44%	12%	0	34	169
22-Aug	56%	33%	0	11%	18	46

HARVEST ESTIMATE

We estimated a total harvest of 2,940 sockeye salmon in the marine area around the mouth of Falls Creek in 2004. Because an interview was conducted with participants from every boat on the fishing grounds, with no missed interviews, the estimate became simply a census of reported harvests. The subsistence harvest of 2,875 sockeye salmon on 33 boats accounted for 98% of the total; the other 2% was harvested by 13 sport fishers. Small numbers of other salmon species were also harvested incidentally (Table 12).

Table 12.–Summary of subsistence and sport salmon harvest and effort at the Falls Lake marine terminal area in 2004. Since all boat groups were interviewed, harvest totals shown in the table represent a complete census, without sampling error (however, sources of non-sampling error may exist).

Gear Type	Boats Counted	Missed interviews	Sockeye	Coho	Chum	Pink	Chinook
Seine	10	0	1,404	0	8	2	0
Gillnet	23	0	1,471	25	219	41	9
Sport	13	0	65	5	0	0	0
Total	46	0	2,940	30	227	43	9

All fishing occurred between 20 June and 28 August, 2004, with subsistence closures from 7–13 July and after 20 July. Subsistence fishing was reopened from 20–31 August, but little fishing took place during this period and few fish were harvested (Table 13). The largest subsistence effort and harvest occurred just after the mid-July closure, with over 1,600 sockeye salmon harvested in 84 total hours of fishing time (Table 12; 14–17 July). Over the whole season, about equal numbers of sockeye salmon were harvested with beach seine and gillnet gear, but the seine harvest was accomplished in just one-third the number of hours of the gillnet harvest.

Table 13.–Number of hours fished and total sockeye harvest by gear type and week, for subsistence and sport fisheries in the Falls Lake marine terminal area in 2004. The dotted line splits the week of 11–17 July into two parts, to show subsistence effort and harvest in the second part of the week immediately following the midseason closure (14–17 July). Sport fishing remained open during this period.

Weeks	Weekly total hours fished				Weekly total sockeye harvest			
	Seine	Gillnet	Sport	All	Seine	Gillnet	Sport	All
20–26 June	-	-	6	6	0	0	0	0
27 June–3 July	14	26	0	39	265	306	0	571
4–10 July	17	7	5	29	113	60	10	183
11–13 July	-	-	0	0	-	-	0	0
14–17 July	9	75	10	94	675	931	18	1,624
18–24 July	4	18	7	29	351	166	19	536
25–31 July	-	-	1	1	-	-	2	2
1–7 August	-	-	1	1	-	-	2	2
8–14 August	-	-	2	2	-	-	2	2
15–21 August	-	-	2	2	-	-	12	12
22–28 August	0	2	0	0	0	8	0	8
Totals	43	127	39	209	1,404	1,471	65	2,940

LIMNOLOGY SAMPLING

Light and Temperature Profiles

The estimated euphotic zone depth (EZD) was the shallowest in early May and deepest in early September, with values near the seasonal average in mid-summer (Table 14). The EZD was unusually deep on 4 September, compared with earlier estimates from this season and from other seasons (Conitz and Cartwright 2005), possibly a result of clear, calm, dry weather through most of the summer.

Table 14.–Euphotic zone depths at Falls Lake, 2004.

Date	Depth (m)
5-May	11.0
16-Jun	13.1
4-Aug	13.0
4-Sep	17.1
Seasonal mean	13.6

The Falls Lake water column was nearly isothermal at about 5°C at the first sampling date of the season, 5 May (Figure 4). A thermocline had developed in Falls Lake between 2–12 m by the 4 August sampling date and persisted through the 4 September sampling date.

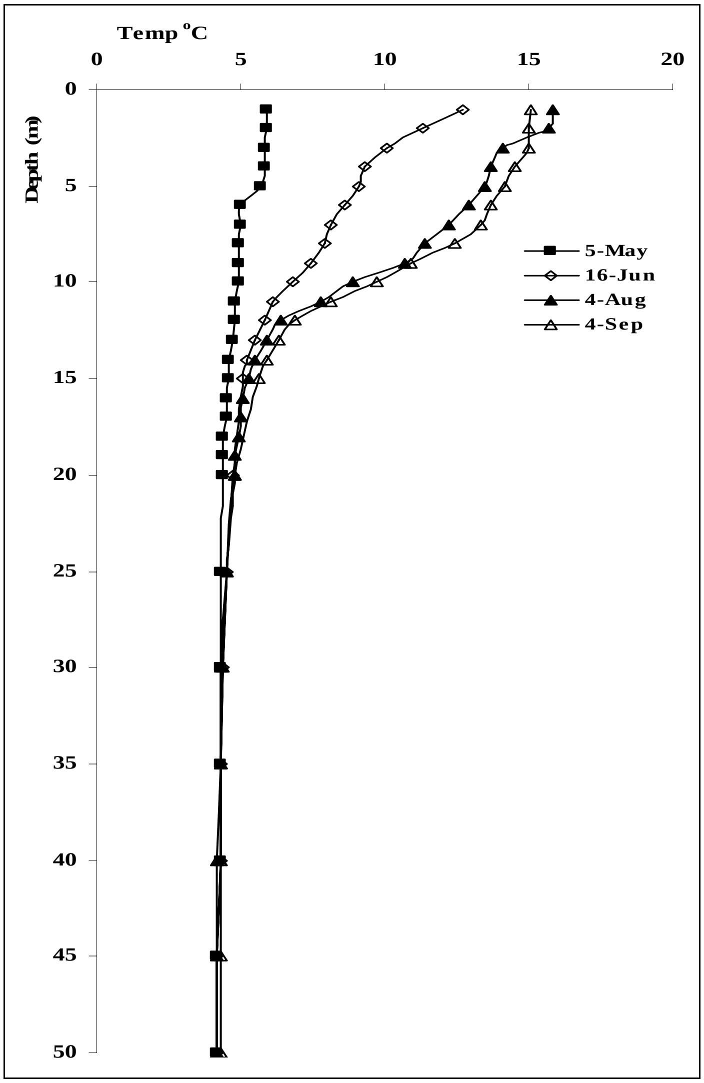

Figure 4.–Water column temperature profiles in Falls Lake, 2004.

Secondary Production

Small-bodied *Bosmina* made up the largest proportion of zooplankton numbers (44%) and biomass (45%) and *Cyclops* made up the next largest proportion (22% of numbers; 35% of biomass) in the Falls Lake zooplankton assemblage in 2004 (Table 15). Density of both major cladoceran groups, *Bosmina* and *Daphnia*, increased dramatically over the summer growing season, to very high numbers in early September relative to overall zooplankton abundance in this lake, whereas copepod density decreased in the late summer.

Table 15.–Falls Lake zooplankton species composition, numerical density, size, and biomass estimates for 2004. Density is average number of zooplankters in the water column, per square meter of surface area, between two sampling stations A and B. Percentage composition of the total zooplankton assemblage by taxon is also shown. Seasonal mean body lengths are weighted by density and averaged between stations A and B. Seasonal mean biomass is a function of seasonal mean body size and density, and percentage composition of total zooplankton biomass by taxon is also shown. Ovigerous (egg-bearing) members of several taxa were counted and measured separately.

	Density (number per m^2), by date								
Taxon	**5/5**	**6/16**	**8/4**	**9/4**	**Seasonal mean**	**Percent of total number**	**Weighted mean length (mm)**	**Seasonal mean biomass ($mg \cdot m^{-2}$)**	**Percent of total biomass**
Epischura	1,252	1,868	425	0	886	4.8%	0.64	1.12	9.5%
Diaptomus	0	0	0	509	127	0.7%			
Cyclops	149	13,118	2,038	1,253	4,139	22.2%	0.54	4.06	34.5%
Nauplii	6,071	4,925	1,528	765	3,322	17.9%			
Bosmina	85	552	9,212	22,457	8,077	43.4%	0.27	5.30	45.0%
Ovig. Bosmina	0	43	170	510	181	1.0%	0.31	0.15	1.3%
Daphnia l.	234	170	764	2,696	966	5.2%	0.52	1.08	9.2%
Ovig. Daphnia l.	0	0	0	255	64	0.3%			
Daphnia r.	127	128	764	255	318	1.7%			
Holopedium	0	0	0	85	21	0.1%	0.56	0.06	0.5%
Immature Cladocera	0	43	849	1,125	504	2.7%			
Seasonal mean totals					**18,605**			**11.78**	

DISCUSSION

Sockeye escapement into Falls Lake in 2004 was in the middle of the range of escapements observed in previous years in this lake. The subsistence harvest of sockeye salmon in the marine terminal area in 2004 was the largest documented in the four years of on-site surveys and twenty years of reporting on returned subsistence permits (Table 16; Conitz and Cartwright 2005). Assuming that all sockeye salmon in the Falls Lake marine terminal area are from the Falls Lake stock, about 47% of the sockeye salmon returning to the Falls Lake system in 2004 were harvested. However, the numbers of sockeye salmon returning to and harvested in the marine terminal area around Falls Lake represent only a portion of the total return and harvest of this stock. An unknown number of Falls Lake sockeye salmon are harvested in commercial fisheries occurring outside of the marine terminal area. These fish in the commercial harvest cannot be distinguished from other sockeye stocks, and so their contribution to the total return and harvest of the Falls Lake stock is unknown.

Table 16.–Summary of marine terminal area harvests and escapements for Falls Lake, for all years with estimates or weir counts through 2004. Escapement estimates in 1981–1989 were simply weir counts, and from 2001–2004 they were mark-recapture estimates.

Year	Total terminal area harvest	Escapement
1981	no estimate	1,278
1982	no estimate	1,687
1983	no estimate	1,656
1984	no estimate	3,622
1985	no estimate	2,612
1986	no estimate	no estimate
1987	no estimate	5,789
1988	no estimate	1,114
1989	no estimate	1,989
-		
2001	2,000	2,600
2002	2,600	1,100
2003	2,700	5,700
2004	2,900	3,300

The midseason closure in 2004 did not appear to be effective in allowing more sockeye salmon to enter the lake before most of the harvest was taken. Only about 100 sockeye salmon were counted through the trap before and during the 7–13 July closure, whereas 750 sockeye salmon were harvested before and over 1,500 immediately after the closure (Appendix B and Table 13). Sockeye salmon returning to Falls Lake may require a period of gradual adjustment to the fresh water, and the area around the base of the falls, with its high volume of freshwater input, does provide such an intermediate environment. The length of time sockeye salmon spend in this area may be determined more by their genetic and physiological adaptations than by variations in environmental conditions. In 2004, a long period of dry, clear weather in midsummer may have helped to keep salmon concentrated near the outlet stream, and certainly made it easier for fishers to travel to Falls Lake and deploy their gear. However, we did not find any obvious evidence that sockeye migration into Falls Lake was delayed by the dry weather. Migration began in mid-July and increased through late July and early August despite low water levels throughout this period (Appendix B). Clearly, fishers target sockeye salmon during the period of peak abundance in the marine terminal area, but we don’t know whether or to what extent this behavior may have selected against earlier migrating fish.

To prevent the disproportionate early harvest of Falls Lake sockeye salmon, ADF&G management biologists planned to try a longer midseason closure in 2005 and monitor escapement during this period. Unfortunately, fishing later in the season is not as desirable from the fishers’ point of view, because sockeye salmon are mixed with other species and usually not as concentrated. For example, in 2004 the late-season reopening of subsistence fishing, in response to widespread spoilage of preserved subsistence salmon in Kake, drew only two boats and resulted in additional harvest of only eight sockeye salmon. Another strategy to protect early escapement may be to move the fishing boundary farther out from the falls.

Age composition estimates in both smolt and adult populations between 2001 and 2004 indicated most ($\geq$ 75%) juvenile sockeye salmon had spent only one year in Falls Lake (Conitz and

Cartwright 2005). In contrast, fish with one freshwater year comprised less than 30%, on average, of 1981–1985 sockeye smolt populations, and just over 50%, on average, of the 1982–1989 escapements (Conitz and Cartwright 2005; Conitz et al. 2002; also unpublished data, ADF&G Div. of Commercial Fisheries). Average weights of both age-1 and age-2 smolt were greater in 2002–2004 than in the 1980s. Changes in sockeye age compositions and smolt sizes between the 1980s and the four years of our study could reflect an increase in lake productivity, possibly because the growing season has become longer and warmer (Edmundson and Mazumder 2001). In addition, intrusion of glacial silt from the main inlet stream may have decreased during this time period as the headwater glacier receded, allowing greater light penetration and thus greater photosynthetic production and increased production at higher trophic levels. The reverse process may have negatively affected sockeye production in Chilkoot Lake, for example (Riffe 2006). Falls Lake was exceptionally clear in 2004, probably a result of the many days of sunny, calm weather during the summer, and the euphotic zone depth was deeper overall, than in previous years (Conitz and Cartwright 2005). The total seasonal mean biomass of zooplankton was the lowest recorded in ten years of sampling (1981–1986 and 2001–2004), and a lower seasonal mean *Daphnia* biomass was recorded only in one year, 2001. Zooplankton and *Daphnia* populations may have been lower than usual because of higher juvenile fish production and increased predation. Sockeye escapement in 2003 was the second highest among years in which it was estimated (Table 16), and this large spawner population most likely produced a larger than usual number of fry in the following year.

By using individual numbered tags, we were able to carefully evaluate model assumptions for a stratified, closed population (Darroch or pooled Petersen) estimate and compare with an open population (Jolly-Seber) model. Estimated capture probabilities were not equal across all initial strata, but we found no other evidence that the Darroch or pooled Petersen estimate might be biased. When we used the Jolly-Seber model to estimate sockeye escapement on the spawning grounds, we obtained an estimate similar to the Petersen. The two estimates were not directly comparable because we used the closed population model to estimate total escapement as fish entered the lake, and the open population model to estimate that portion of the spawning population within a designated study area. Furthermore, we used each method to estimate the population at a different time. Because the closure assumption was relaxed in the closed population model to allow death, the estimate applied to the population at the time of the first sample, i.e. sockeye salmon entering the lake. In contrast, the open population model applied to sockeye salmon on the spawning grounds, at a time as long as 6–8 weeks after their entry into the lake. Some mortality may have occurred between the time sockeye salmon first entered the lake and the time at which they appeared in the spawning areas. For example, field notes from Falls Lake weir operations in the 1980s indicate a number of mortalities at the weir, which at that time was located below the upper falls. Some of these mortalities could have been fish that died from stress-related causes after ascending the upper falls. Natural mortalities such as these would result in a population of fish on the spawning grounds smaller than the number that entered the lake.

We concluded that a closed population model may be adequate for estimation of sockeye escapement into Falls Lake provided that mark-recovery sampling thoroughly covers the spawning season and the main spawning areas. However, closure assumptions in the closed population model must be relaxed to allow death in spawning salmon populations, and if capture probabilities are also unequal, the estimate may be biased high (Arnason 1996). Furthermore, we are estimating escapement at the time of entry into the lake, which may be greater than the spawning population size if some natural mortality occurs before fish arrive on the spawning grounds. The Jolly-Seber model may be more appropriate for spawning salmon populations because it does not require closure with respect to immigration or death, and it allows survival and capture probabilities to vary between sampling events. However, if as in 2004 we sample within a study area that contains only part of the sockeye spawning population, we must use unverified visual estimates to extrapolate the study area estimate to the whole spawning population. Extrapolation, or expansion, based on visual estimates introduces a potentially large source of error that is difficult to quantify. In the future, sampling on the spawning grounds could be extended to include all spawning areas, and then an open population estimate could be considered an estimate of the total sockeye spawning population.

In summary, the 2004 sockeye escapement at Falls Lake was well within the range of previous years' observed escapements despite a record high terminal area harvest at the beginning of the run. Management biologists' attempt to regulate the timing of harvest with respect to escapement using in-season closures was not successful. Very low zooplankton populations in Falls Lake warrant continued observation of freshwater production and environmental variables in conjunction with escapement estimation. The lake may be more productive in the early 2000s than it was in the 1980s, as evidenced by an apparent increase in proportions of sockeye salmon with just one freshwater year. Changes in the physical environment of the lake including less glacial input, clearer water, and warmer temperatures may have allowed greater zooplankton production compared with the 1980s. At the same time, any increased zooplankton production was apparently being consumed by the existing sockeye fry population, as evidenced by very low zooplankton density and biomass estimates. Therefore, we doubt if Falls Lake could support a much larger sockeye fry population under conditions observed in 2001–2004, or if fry numbers did increase, we would expect average weight and proportion smolting at age 1 to decrease.

This small sockeye stock has a high cultural significance and continues to provide an important traditional food source for the people of Kake. We recommend continued monitoring of sockeye escapement and subsistence and sport harvest, at minimum, to provide fishery management biologists with a continuing time series of escapement and harvest estimates with which to compare escapement and harvest sizes in the future. Management biologists face the challenge of balancing the needs of subsistence users from Kake with sustainability of the stock, and have no way to gauge the effectiveness of management actions without reliable numerical estimates. Additionally, federal subsistence biologists have cited commercial fishing statistics to support their opinion that this stock is under increasing pressure from commercial fisheries targeting increased salmon production from nearby hatcheries (B. Van Alen, presentation to the Southeast Regional Advisory Council, October 2005; Larson 2001). We also recommend continued study of juvenile sockeye populations and freshwater habitat to the extent possible to improve our understanding of the population dynamics of this small Southeast Alaska stock. Falls Lake is one of the most important sockeye systems in the southern Chatham Strait area, and the only one with a monitoring program of more than three years' duration. With continued or increasing pressure from subsistence, sport, and commercial fisheries in this area, monitoring at least some of the smaller sockeye stocks is extremely important. A detailed understanding of the dynamics of at least one system will help biologists to better assess the results, in terms of sockeye production, of their actions to control the size and timing of sockeye harvests.

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APPENDICES

Appendix A.–Daily counts of sockeye and coho smolts and other fish caught in the fyke-net trap in the Falls Lake outlet stream in 2004, with total hours fished (starting at 2030 hours daily), number of sockeye smolt sub-sampled for age-weight-length (AWL), and water level and temperature at the head of the outlet stream.

	Fish counts by species								
Date	**Sockeye smolt**	**Coho smolt**	**Dolly Varden**	**Stickle-back**	**Sculpin**	**Total hours fished**	**AWL samples (sockeye)**	**Water Level (ft)**	**Water Temp. (oC)**
26-Apr	3	3				3.5	3	1.4	4.5
27-Apr	0	1				3	0	1.2	4.5
28-Apr	21	6				3	21	0.9	5.0
29-Apr	34	5				3	34	0.7	6.0
30-Apr	32	6				3	32	0.7	6.0
1-May	73	8	1			3	40	1.0	6.5
2-May	265	11				3	40	1.2	5.5
3-May	631	20	2			24	0	1.5	6.0
4-May	326	11	3			24	40	1.1	7.5
5-May	701	18		2		24	67	1.0	5.0
6-May	402	5	1			4	0	0.9	6.0
7-May	88	2				4	28	0.8	6.0
8-May	719	5			1	4	56	0.8	7.0
9-May	286	6			1	4	56	0.7	8.0
10-May	178	0				4	0	0.7	7.5
11-May	1,131	37	5	2		24	68	0.8	8.5
12-May	743	65	22			24		0.9	9.0
13-May	244					6		0.9	10.0
14-May	128	36	15	1		6		1.0	10.0
15-May	74	21	17	3		6		0.9	10.0
16-May	164	18	4			6	28	0.8	10.0
17-May	109	19	8			6	28	0.9	11.5
18-May	120	24	10	1		24	28	0.8	11.5
19-May	92	31		1		24		0.9	12.0
20-May	49	11	6	1		6	28	0.9	11.5
21-May	39	24	15		1	6		1.0	10.0
22-May	31	15	4			6	8	1.0	11.0
23-May	23	2	1			6	20	1.0	9.5
24-May	32	8	7	1	1	6		1.0	11.0
25-May	35	10		2		24		1.0	11.0
26-May	19	5		2		24		1.1	12.0
27-May	14	4		3		6	14	0.9	10.0
28-May	13	2	2	2		6	2	0.8	12.5
29-May	4	2	1			6		0.8	12.0
30-May	3	2				6		1.2	12.0
31-May	2	1	3	2	1	6		1.2	11.0
1-Jun	10		4			6		1.1	11.0
2-Jun	6	1	3			6		0.9	10.0
3-Jun	4					6		0.8	11.0
4-Jun	3	1				6		0.8	12.0
5-Jun	2					6		1.0	11.0
6-Jun	1	0	2			6	1	1.0	11.0

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Appendix A.–Page 2 of 2.

		Fish counts by species							
Date	**Sockeye smolt**	**Coho smolt**	**Date**	**Sockeye smolt**	**Coho smolt**	**Date**	**Sockeye smolt**	**Coho smolt**	**Date**
7-Jun	6	0	0			6	6	1.0	10.5
8-Jun	0	1	2		1	6	0	1.0	10.5
9-Jun	0	0	1			6	0	0.9	12.0
10-Jun	3	0	0			6	3	0.8	12.5
11-Jun	0	0	0			6	0	0.7	13.0
12-Jun	1	0	0			6	1	1.4	12.0
13-Jun	1	1	0			6	0	1.4	11.5
14-Jun	0	0	0			6	0	1.1	11.0
15-Jun	1	0	0			6	0	0.9	11.0
16-Jun	1	0	0			6	1	0.9	13.5
17-Jun	1	0	0			6	0	1.0	13.5
18-Jun	1	0	0	4		6	0	1.0	13.5
19-Jun	0	1	0			6	0	1.0	14.5
Totals	**6,869**	**449**	**139**	**27**	**6**	**462**	**653**		

Appendix B.–Daily and cumulative counts of adult sockeye and coho salmon entering Falls Lake through the fish ladder, and associated water levels and water and air temperatures, for 2004.

	Sockeye Salmon		Coho Salmon		Physical Data			Other Fish	
Date	Daily	Cumulative	Daily	Cumulative	Water level (mm)	Water temp (°C)	Air temp (°C)	Daily Count	Species
20-Jun	0	0	0	0	305	16	19		
21-Jun	0	0	0	0	293	16	20		
22-Jun	0	0	0	0	274	14	19		
23-Jun	0	0	0	0	268	16	16		
24-Jun	0	0	0	0	268	14	16		
25-Jun	2	2	0	0	268	15	15		
26-Jun	0	2	0	0	262	16	14		
27-Jun	0	2	0	0	244	15	14		
28-Jun	0	2	0	0	238	16	15		
29-Jun	0	2	0	0	219	16	16		
30-Jun	0	2	0	0	219	16	16		
1-Jul	0	2	0	0	219	16	13		
2-Jul	0	2	0	0	213	17	15		
3-Jul	0	2	0	0	213	16	14		
4-Jul	0	2	0	0	207	17	15		
5-Jul	0	2	0	0	213	16	14		
6-Jul	0	2	0	0	271	15	13		
7-Jul	0	2	0	0	244	16	17		
8-Jul	2	4	0	0	226	15	13		
9-Jul	0	4	0	0	219	15	13		
10-Jul	0	4	0	0	207	16	14		
11-Jul	7	11	0	0	207	16	15	1	Dolly Varden
12-Jul	14	25	0	0	201	16	17		
13-Jul	51	76	0	0	201	17	18		
14-Jul	44	120	0	0	201	16	17		
15-Jul	25	145	0	0	201	18	19		
16-Jul	36	181	0	0	201	19	19		
17-Jul	23	204	0	0	207	18	15		
18-Jul	0	204	0	0	207	18	12		
19-Jul	5	209	0	0	189	18	18		
20-Jul	38	247	0	0	189	18	16		
21-Jul	15	262	0	0	189	18	16		
22-Jul	25	287	0	0	183	18	16		
23-Jul	51	338	0	0	177	18	16		
24-Jul	110	448	0	0	183	18	18		
25-Jul	59	507	0	0	189	19	17		
26-Jul	26	533	0	0	189	18	15		
27-Jul	50	583	0	0	183	18	16	2	Dolly Varden
28-Jul	11	594	0	0	189	18	16		
29-Jul	23	617	0	0	201	17	16	1	Dolly Varden
30-Jul	30	647	0	0	201	18	16		
31-Jul	21	668	0	0	183	17	15		
1-Aug	101	769	0	0	177	18	15	1	Dolly Varden
2-Aug	56	825	0	0	183	17	14	1	Dolly Varden
3-Aug	223	1,048	8	8	381	17	14	2	Dolly Varden
4-Aug	156	1,204	8	16	323	16	14		

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	Sockeye Salmon		Coho Salmon		Physical Data			Other Fish	
Date	Daily	Cumulative	Daily	Cumulative	Water level (mm)	Water temp (°C)	Air temp (°C)	Daily Count	Species
5-Aug	46	1,250	3	19	232	17	14		
6-Aug	21	1,271	0	19	201	16	14		
7-Aug	8	1,279	0	19	195	16	14		
8-Aug	5	1,284	0	19	189	17	16		
9-Aug	13	1,297	0	19	177	17	16		
10-Aug	30	1,327	1	20	177	18	19		
11-Aug	19	1,346	0	20	177	17	17		
12-Aug	10	1,356	0	20	171	17	17		
13-Aug	17	1,373	0	20	165	18	18	1	Dolly Varden
14-Aug	12	1,385	0	20	165	18	20		
15-Aug	27	1,412	1	21	165	19	19		
16-Aug	26	1,438	0	21	177	19	22		
17-Aug	37	1,475	0	21	177	20	17		
18-Aug	25	1,500	1	22	183	19	16		
19-Aug	23	1,523	0	22	183	18	16		
20-Aug	17	1,540	1	23	189	17	15		
21-Aug	14	1,554	4	27	177	18	16		
22-Aug	4	1,558	1	28	171	18	19		
23-Aug	14	1,572	2	30	165	18	16		
24-Aug	2	1,574	2	32	165	18	14		
25-Aug	4	1,578	0	32	146	17	16		
26-Aug	7	1,585	0	32	146	18	17		
27-Aug	10	1,595	5	37	183	17	17		
28-Aug	5	1,600	1	38	183	17	16		
29-Aug	8	1,608	2	40	168	17	16		
30-Aug	0	1,608	0	40	168	17	15		
31-Aug	12	1,620	6	46	168	17	16	1	Chinook
1-Sep	6	1,626	14	60	168	17	17		
2-Sep	7	1,633	5	65	140	17	14		
3-Sep	3	1,636	9	74	247	17	14		
4-Sep	4	1,640	46	120	271	15	12		